HISTORICAL CHANGES IN THE LOWER COLUMBIA RIVER

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Abstract

The Columbia River is an important resource to the states of Oregon and Washington, providing both economic and environmental benefits. The Lower Columbia River provides a deep-draft navigation link between Portland, OR/Vancouver, WA, and the Pacific Ocean. This reach of river, especially the estuary, also supports a variety of fisheries, including salmon, steelhead, sturgeon, and crabs.

Since the 1800's the Lower Columbia River's streambed and sediment processes have undergone changes caused by both human and natural causes. Major actions have affected the river included: construction of jetties at the mouth of the river, diking and filling of wetlands for urban and agricultural uses, development of the deep-draft navigation channel and a series of upstream reservoirs for hydropower and flow regulation. There has also been a natural decline in annual and spring-freshet discharges. These factors have combined to produce a river that is now narrower and deeper than it was in the early 1800's, with less flooding and reduced annual sand transport capacity.

Introduction

The Columbia River is an important resource to the states of Oregon and Washington, providing both economic and environmental benefits. The Lower Columbia River, shown in Figure 1, provides a deep-draft navigation link between Portland, OR/Vancouver, WA, and the Pacific Ocean. This reach of river, especially the estuary reach downstream of river mile (RM) 40, also supports a variety of fish and wildlife, including endangered salmon, steelhead, bald eagles, and Columbian white-tailed deer. Habitats for these species have been altered by human development along the river and there is now interest in restoring lost habitat. The physical changes that have occurred along the river were examined during the Corps' Columbia River Channel Improvement Biological Assessment, (2001) and Final Supplemental Integrated Feasibility Report and Environmental Impact Statement (2003).

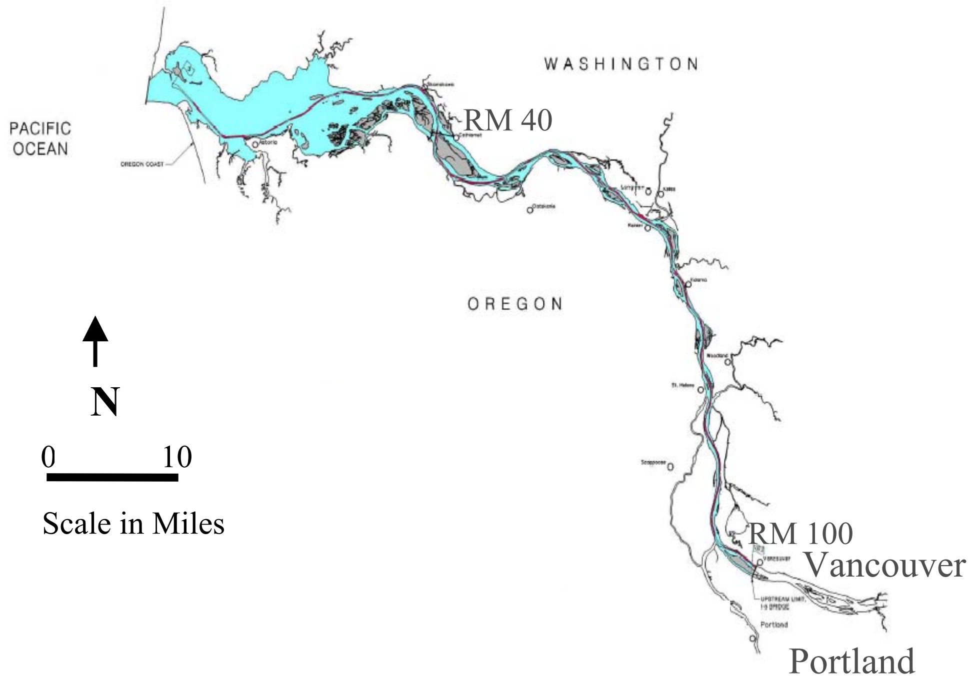


Figure 1. Area Map of the Lower Columbia River.

Since the 1800's the Lower Columbia River's channel and floodplains have undergone changes caused by both human and natural causes. Major actions that have affected the river included: construction of jetties at the mouth of the river, diking and filling of wetlands for urban and agricultural uses, development of the deep-draft navigation channel and a series of upstream reservoirs for hydropower and flow regulation. There has also been a natural decline in annual and spring-freshet discharges. These factors have combined to produce a river that is now narrower and deeper than it was in the early 1800's, with less flooding and reduced annual sand transport capacity.

Hydrology

The Columbia River drains 259,000 square miles, originating in Canadian Rockies. The hydrology of the upper basin is dominated by snowmelt, resulting in low winter discharges and large spring freshets. Heavy winter rainfall in the lower basin can cause high discharges in the lower river. Figure 2 shows the average annual discharge for 1879-1999, measured by the U.S. Geological Survey at The Dalles, OR, (River Mile 194). The Columbia's average annual discharge for the entire period of record is 192,000 cubic feet per second (cfs).

Within the 1879-1999 period of record, there are four distinct intervals that are significant to the assessing environmental change in the lower Columbia River. The first two intervals cover unregulated flows during 1879-1899 and 1900-1935. The third interval is 1935-1974, a period of major reservoir construction and irrigation development. The final interval is 1975-1999, a time of maximum irrigation development and fully operational flow regulation.

The first interval is a high flow period prior to 1900. During this time the average annual discharge at The Dalles, was 222,000 cfs, well above the period of record average of 192,000 cfs. Three of the four highest runoff years occurred during this early period. During the second interval (1900-1935), river flows remained essentially natural and climate variations caused the average annual runoff to fall to 187,000 cfs. During the third interval (1935-1974) there were a series of incremental increases in flow regulation and irrigation diversions as new projects came online. Annual discharge continued to average 187,000 cfs during this interval, despite the increases in irrigation diversions. During the latest interval, (1975-1999) the average annual discharge dropped to 181,000 cfs. Jay and Naik, (2000) found that for this period of maximum water resource development, the decline in average annual discharge from the late-1800's level can be attributed nearly equally to global scale climate variations and the upstream irrigation diversions.

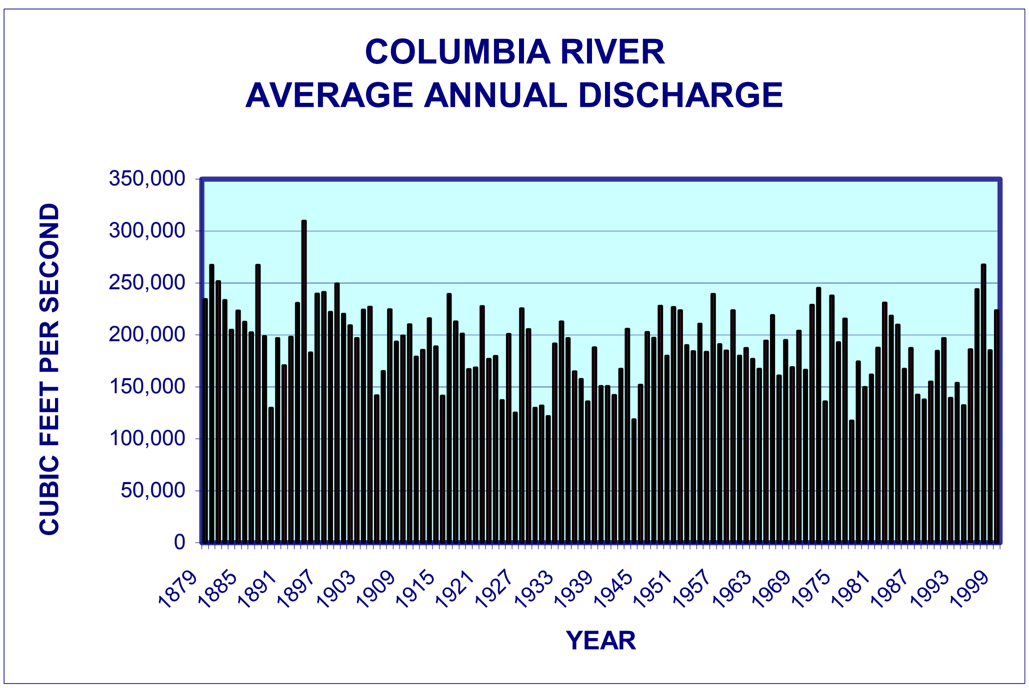


Figure 2. Average annual Columbia River discharge at The Dalles, Oregon, from USGS streamflow records.

In addition to changes in average annual discharge, since 1975 there have also been large reductions in the annual spring freshet discharges. Reservoirs on the Columbia and its tributaries provide flood regulation and energy production by storing water during the spring snowmelt and releasing it during the fall and winter for hydroelectric power generation. Flow regulation began with Grand Coulee in 1941, but did not become fully operational until the mid-1970's with the completion of several large upper basin projects, including Mica and Arrow in British Columbia and Libby in Montana. The 2-year flood peak at the Dalles, Or, has been reduced from 580,000 cfs without regulation, to 360,000 cfs with regulation **(**USACE, 1987**)**. The lower spring freshet discharges have affected salmon migration, reduced flooding of streambank habitats, and reduced sand transport in the lower river and estuary.

Sedimentation

Sedimentation is an important factor in the habitat forming processes of the lower Columbia River. Fine grained sediments help provide nutrients and sand deposition builds new shallow water and wetland habitats. The changes over time to fine grained sediment supply are unknown. However, there has been a large reduction in sand transport since the 1800's.

Sediment Supply. Over the past 10,000 years, the lower Columbia River valley has filled with deep alluvial deposits of sand, with some silt and gravel (Gates, 1994). The fine grained sediment supply to the lower Columbia River comes mainly from the upper basin, east of the Cascade Mountains. Streams flowing from the volcanic Cascades mountains have produced most of the sand supply (Whetten et al., 1969). The bed of the main river channel is composed of deep deposits of mostly fine and medium sand (0.125-0.50 mm), finer sediments make up less than 5 percent of the bed material in the main river channel. The natural riverbanks consist of basalt or erosion resistant sand, silt, and clay deposits. The location of the river channel had been stable for 6,000 years (USACE, 1986).

Sand Transport. Given the abundant supply of sand in the riverbed downstream of Bonneville Dam, sand transport in the lower Columbia River is driven by the river discharges. Sherwood et al. (1990) used available discharge and suspended sediment data to hindcast total sand transport for the lower Columbia River as far back as 1879. Bottom et al. (2001) extended the annual total sediment discharge estimate to 1999. Figure 3 shows the resulting annual Columbia River total sand transport hindcast for 1879-1999 derived from those two studies. Bedload transport makes up only a fraction of the total sand transport, but is an important factor in navigation channel shoaling.

On an annual basis, sand transport in the lower Columbia River has been highly variable, ranging naturally from about 0.1 mcy in 1926 to over 37 mcy in 1894, amplifying the variations in the river discharges. However, in the long-term, lower discharges and reservoir flow regulation have caused persistent reductions in annual sand transport in Columbia River. The high discharges prior to 1900 produced an average total sand transport of 9.1-mcy/yr. The lower natural streamflows during 1900-1935, cause the total sand transport for the period to fall to an average of 3.8 mcy/yr. Sand transport dipped slightly to an average of 3.2 mcy/yr during 1936-74, even though the average annual discharges for the 1900-1935 and 1936-1974 intervals were the same. However, since 1975, flow regulation has significantly reduced spring freshet discharges and consequently the average annual sand transport has declined to only 1.3 mcy/yr.

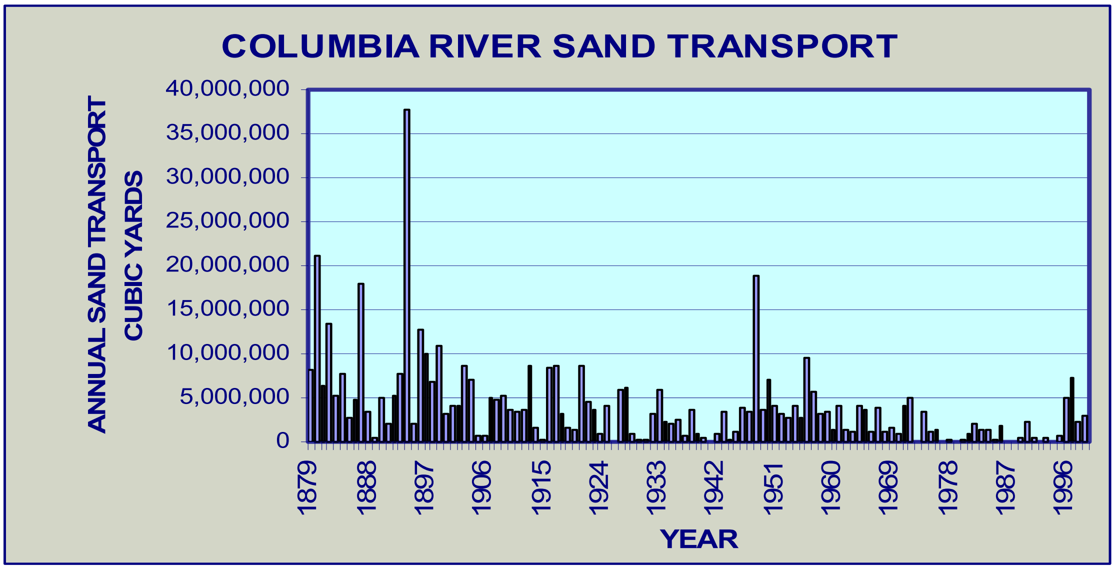


Figure 3. Columbia River annual total sand transport at Vancouver, Washington, upstream of the Willamette River. Derived from Sherwood et al. (1990) and Bottom et al. (2001).

In planning for ecosystem restoration, it would be helpful to attribute sand transport reductions to climate change, irrigation diversion, and flow regulation. Jay and Naik (2000) found that because of the non-linear dependence of sand transport on flow, the changes could not be precisely distributed among those three factors. However, examining the four selected time intervals can provide some indications of influence of the climate variation and flow regulation. Comparing the two intervals of unregulated flow, 1879-1899 and 1900-1935 provides an indication of the potential influence of climate variation on sand transport. While irrigation diversions may have had some small influence on reducing annual discharges during 1900-1935, they would have had minimal impact on the freshet flows that transport most of the sand. Thus the 16% decline in average annual discharge and the nearly 60% decline in sand transport between those two intervals can be attributed to lower natural streamflows caused by climate variations. The 1935-74 interval does not provide any clear evidence of the influence of the contribution of climate variation, flow regulation by upstream reservoirs or irrigation diversions because they all made varying contributions to the reductions in sand transport. Since 1975, climate and irrigation diversions have contributed to producing the lowest average annual discharge of any of the four time periods examined in this analysis. However, the largest change during this interval is the significant reduction in spring freshet discharges because of effective flow regulation by upstream reservoirs. Consequently, the 60% reduction average annual sand transport from the 1935-1974 level can be attributed mainly to flow regulation. The affect of flow regulation on sand transport can be seen in the high annual runoff, but relatively low sand transport that occurred in 1996 and 1997.

Erosion/Accretion. There is little information available about sediment erosion or accretion volumes along much of the lower Columbia River. Sediment volume changes are only known for the estuary portion of the Columbia River, for the time periods 1879-1935 and 1935-1958 (Sherwood et al, 1984). The average annual estuary accretion rate was 5.0 mcy/yr from 1879-1935 and 3.3 mcy/yr for 1927-1958. That decline corresponds to lower streamflows and the associated reduction in sand transport in the river. There may also have been reduced sand inflow from the mouth of the Columbia River (MCR) due to the construction of the entrance jetties (USACE, 2003).

The long-term accretion of river sand on the south side of the estuary between RM 20-40, has built a complex network of islands and shallow channels in Cathlamet Bay. Sherwood et al, (1984) calculated sediment accretions in Cathlamet Bay of 65 mcy (1 mcy/yr) and 35 mcy (1.5 mcy/yr) respectively for the time periods 1879-1935 and 1935-1958. This area was of particular interest during the Endangered Species Act consultation for the Columbia River Channel Improvement Project (USACE, 2001) because it provides important shallow water habitat for endangered salmon, steelhead, and bald eagles. With the average annual sand transport in the Columbia River reduced to less than 1.5 mcy/yr, there is likely to be a corresponding decline in sand accretion in Cathlamet Bay and alteration of the habitat forming processes.

Navigation Development

Major navigation development began with the construction of the MCR jetties between 1886 and 1917. In the river, the first major work began in 1914 with the initiation of construction of the 30-ft channel and related flow control measures. Those actions, and subsequent improvements, have altered the depth and width of the MCR and river.

MCR Jetties. Prior to jetty construction at the MCR, the ebb-tidal delta was over 6 miles wide and was located close to the MCR in very shallow water. At least two channels existed through the entrance, with average depths over the ebb tidal delta of about 25 ft (USACE 1999). The location of the channels was very dynamic, changing from year to year.

Construction of the MCR jetties changed the inlet hydraulics and sand transport. The inlet narrowed, and by 1924 a single deeper channel with a depth over 33 ft had formed. The current controlling depth is maintained at approximately 55-ft MLLW by dredging and the hydraulic conditions created by the jetties. Twenty years after jetty construction, the ebb-tidal delta had moved more than 10,000 ft offshore from MCR, into deeper water (USACE 1999) and nearly 800 mcy of sand eroded from the inlet and vicinity, and deposited along the coast (Gelfenbaum and Kaminsky, 2000 and Gelfenbaum, et al, 2001). The MCR jetties and the resulting changes to inlet bathymetry also reduced the sand transport into the estuary caused by ocean waves.

Navigation Channel. Prior to navigation channel development, much of the main river channel already had natural thalweg depths in the 35- to 45-foot range. However, the controlling depth (minimum depth available anywhere along the navigation channel) was only 12-15 feet (Hickson, 1961). Because of the naturally occurring depths, only minor dredging was conducted in the river to maintain a 25-ft channel prior to 1914.

In 1914, work began on the 30-ft deep by 300-ft wide navigation channel and related river control measures. Numerous pile dikes and in-water fills were built along the river to constrict the channel, decrease flow into some of the side channels, and to stabilize the navigation channel alignment. Pile dikes were usually built in a series of dikes spaced 1,200-1,500 feet apart, which run along the shoreline for up to four miles. The navigation channel was improved to 35-ft deep by 500 ft wide in 1935 and to 40-ft deep by 600 ft wide in 1976. Additional pile dike fields were built between 1965 and 1976. Navigation channel dredging records indicate that nearly 700 mcy of sediment has been dredged from the river and estuary (RM 3-106) between 1900 and 2002 (USACE, 2002).

By 1924, the combination of dredging and river control measures had begun to lower bed elevations in the shallow reaches of the river channel. Figure 4 shows three examples of constructed channel constrictions and the resulting channel changes that occurred between 1909 and 2001. In these areas, much of the dredged sand was disposed of within the pile dike fields, producing the sediment accumulations shown along the shorelines at RM's 99 and 70. Dredged sand disposal sites now line half of the Columbia River shoreline between RM's 21 and 106. The shoreline disposal has displaced the natural shoreline habitats with unstable sandy beaches (USACE, 1999). The land created by shoreline disposal is used for a variety of activities, including agriculture, port and industrial development, recreation, and residential dwellings.

Figure 4 shows that a different approach was taken at RM 42. There the navigation channel was moved from the right side (Washington side) of the river to the left side and disposal was used to construct an island. Inactive disposal islands provide habitats ranging from wetlands to upland grassland.

As shown in Figure 4, the riverbed has generally deepened in response to the deepening of the navigation channel. The increases in depths extending across the riverbed are due to the deflection of bedload into the deeper navigation channel and the subsequent removal of the resulting shoal by maintenance dredging (Eriksen and

Gray, 1991). By the 1999, thalweg depths had increased to near 50 feet throughout most of the river downstream of Portland/Vancouver (RM 106). Upstream of Portland/Vancouver the navigation channel is maintained to only 17 ft deep. Only minor dredging occurs in the shallow channel and the riverbed has changed relatively little in the last 130 years.

Estuary Habitat Losses

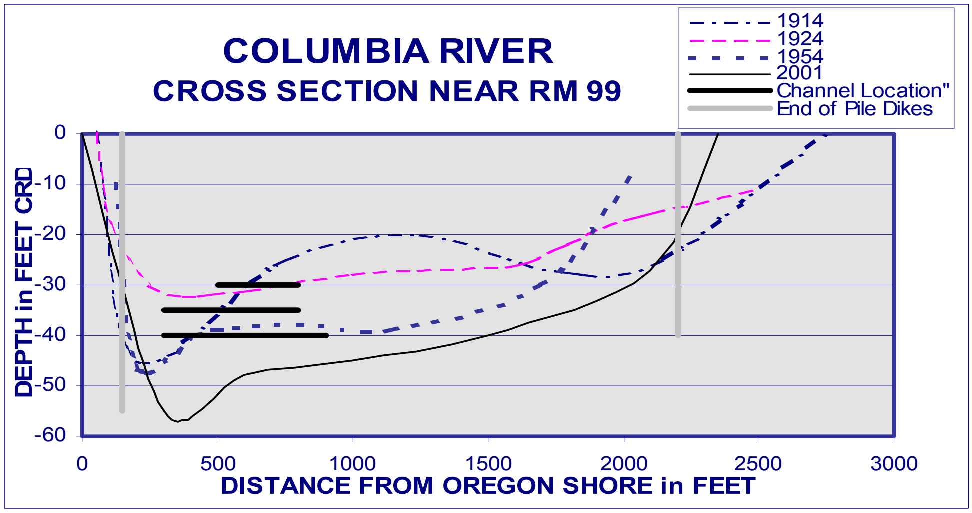
Some of the most important habitat losses have occurred in the estuary (downstream of RM 46). Tomas (1983) prepared an inventory of lost habitats and the major causes. Between 1870 and 1980, 7,000 acres of tidal marsh and 23,100 acres of tidal swamp habitats were lost. These lands are located around the periphery of the estuary and on estuary islands. Most of the land, 24,000 acres, was diked and converted to upland uses, such as agriculture and urban development. In the estuary, navigation development filled 800 acres of shallow water habitat, but because of the natural infilling of estuary channels, there was an overall gain of 4,100 acres of shallow water habitat.

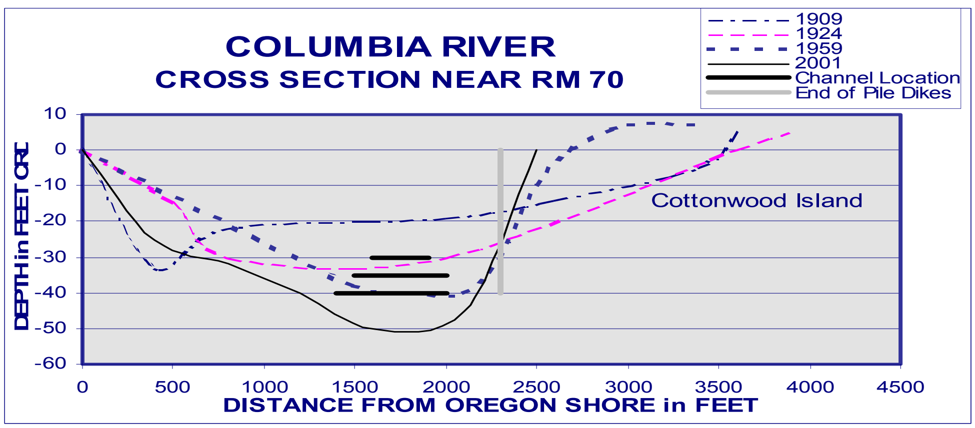
Conclusions

Over the past 120 years, the lower Columbia River has been influenced by a number of human and natural events. Hydrologic changes have caused a corresponding reduction in annual sand transport in the river and the MCR. Annual runoff in the river has declined because of global scale climate variations and irrigation diversions. The spring freshet discharges have been regulated by upstream reservoirs, further affecting sand transport potential in the river.

Downstream of Portland/Vancouver, the river channel alignment has been altered slightly and the riverbed is generally narrower and deeper than it was before the development of the deep-draft navigation channel. Natural habitats have been displaced by dredged sand disposal along half the river's shoreline. Important tidal marsh and swamp habitat has been lost in the estuary primarily because of diking and filling for upland conversion.

The diked lands along the lower river and estuary present the best opportunities for restoring historic habitats that have been altered due to both human and natural events. When designing a restoration project, however, consideration should be given as to how the natural and human changes in hydrology and sand transport have altered the habitat forming processes that would support habitat restoration.





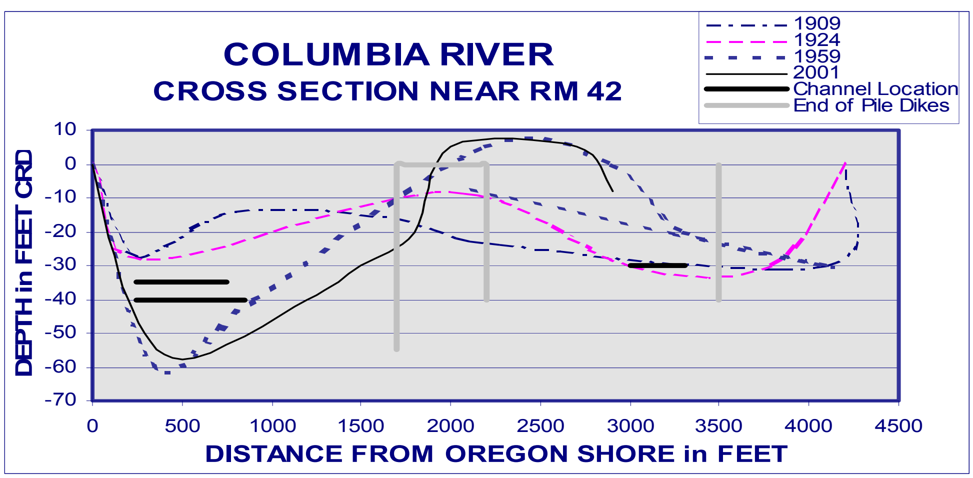


Figure 4. Changes to Columbia River cross-sections resulting from navigation channel development.

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